Urban Heat Islands and sustainable urbanity

Emmanuel, Rohinton

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CITY Weathers

meteorology and urban design 1950-2010

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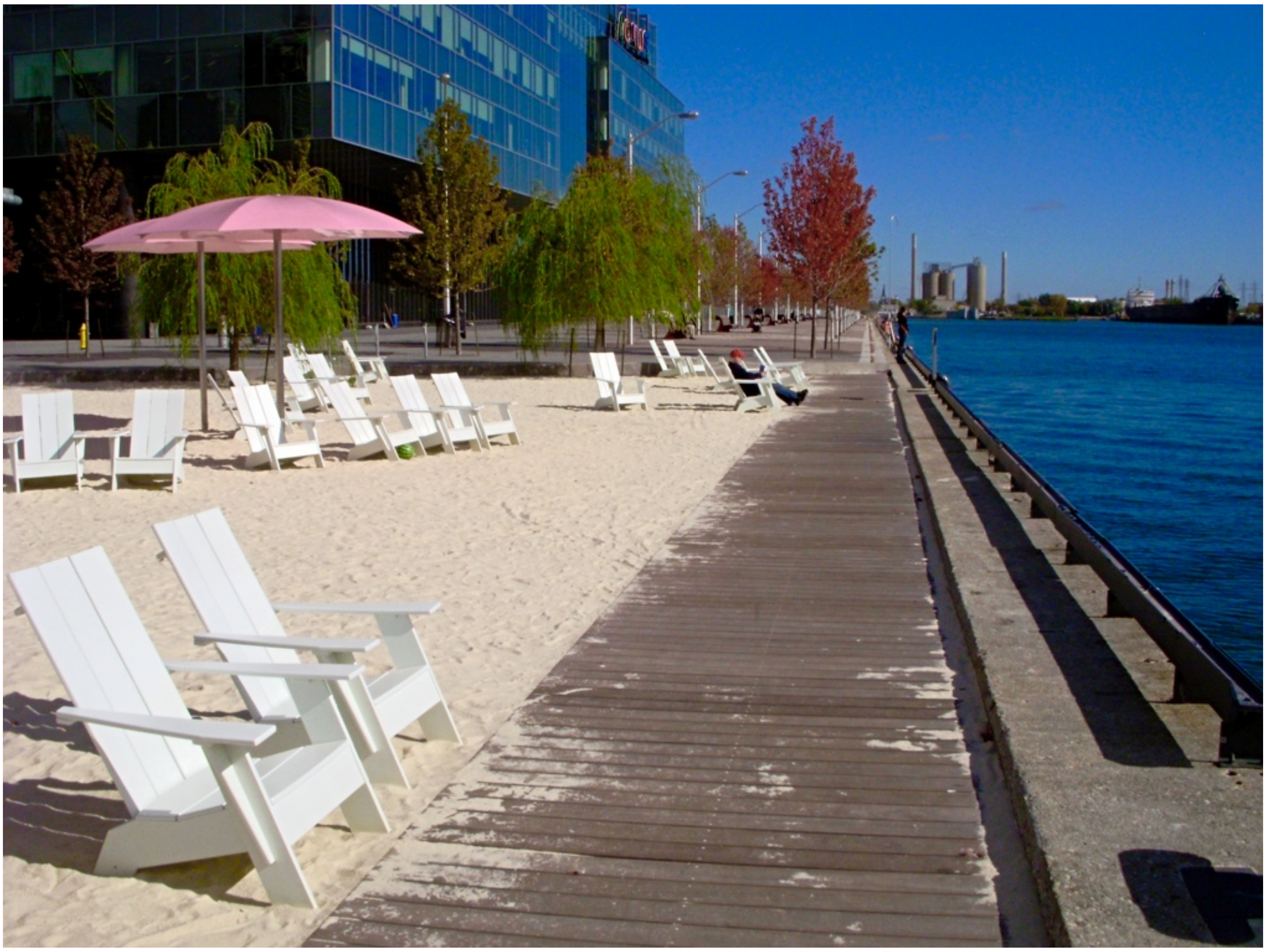

Contents

Urban Heat Islands and sustainable urbanity: An application agenda for tropical mega-cities

Rohinton Emmanuel

Urban growth across the world remains unstoppable; more than half of the world's population already live in cities and especially in Africa and Asia, the next two decades will see a doubling of urban population over that at the start of this century. This is equivalent to the accumulated urban growth in the entire civilizational history of these continents (UNFPA, 2010). By 2030, global urban population will be nearly 70% of the total population (UN, 2010), and 80% of urban humanity will live in the developing world (UNFPA, 2007). Such rapid urban growth contributes to anthropogenic global climate change due to higher consumption of energy and materials as well as associated pollution and waste generation. Some estimates (for example, Svirejeva-Hopkins, 2004) suggest that up to 90% of all carbon emission originate in cities. Yet, the role of cities is missing in climate change model projections, as acknowledged by the Intergovernmental Panel on Climate Change (Christensen et al., 2007). Given these realities many now see cities as critical linchpin in the efforts to adapt/mitigate global climate change (Mills 2006; Grimmond, 2007; Grimmond et al., 2010). The rate of urban growth in the developing world (much of which is in the warm belt) makes the role of tropical cities in the global action to adapt to climate change even more important.

Given the demographic and social importance of warm cities, could we direct urban growth in warm places to mitigate the heat island effect and simultaneously enhance their adaptive capacity to global warming? What urban design options work best to enhance the outdoor comfort in warm humid places? How do we promote higher density urban living in the warm humid belt without compromising human wellbeing?

Evidence for urban warming in warm, humid regions

Although urbanisation is at its most intense in the warm humid belt (approx ±20o from the equator), urban climate studies from this region lag far behind those from the temperate zone. Surveying the relevant literature Roth (2007) concluded that less than 20% of all urban climate studies concern either the tropical or sub-tropical regions. A survey of the bibliographical database maintained by the International Association of Urban Climate (www.urban-climate.org) for the period of 2007-2010 showed that only 21 out 661 studies published during this period are concerned with the warm-humid region. Of these only 12 are directly relevant to the outdoor conditions in the warm-humid urban tropics.

One of the earliest UHI studies in warm, humid cities was conducted by Nieuwolt in Singapore in the mid-1960s (Nieuwolt, 1966). Since then Jauregui (Jauregui, 1993; 1996) has published two special bibliographies on tropical UHI studies. An update of key studies up to and including 2004 was provided by Emmanuel (2005).

Thermal comfort in warm, humid outdoors

The practice of applying universal thermal comfort indices to analyse the thermal conditions in the tropics continues to be the norm. Studies specifically estimating the outdoor comfort conditions in the tropics are very rare. The few that exists confirm that warm, humid dwellers typically prefer higher temperatures and have greater tolerance to warming. One of the earliest such studies was conducted in Dhakka, Bangladesh (Ahmed, 2003) (Figure 1). An outdoor temperature range of 27.5 – 32.5oC under calm conditions was considered 'acceptable' in Dhaka when the relative

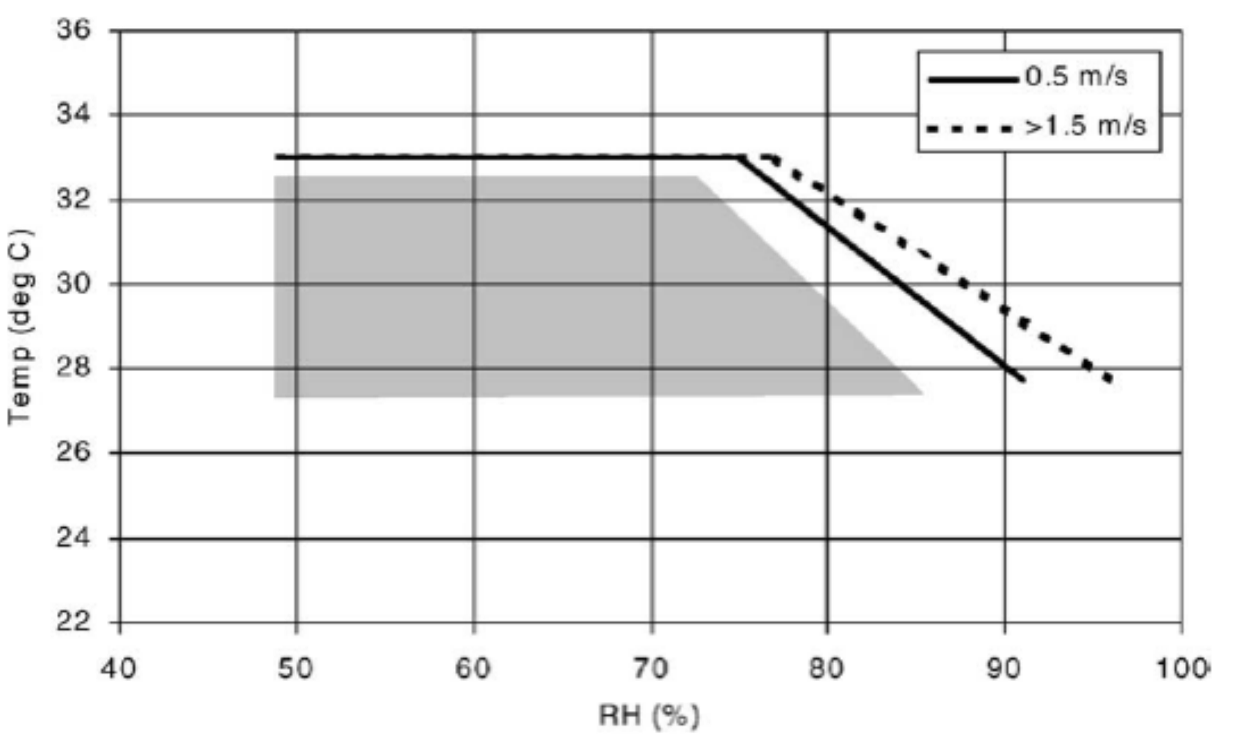

Figure 1: Outdoor comfort zone in a warm, humid city (Dhaka, Bangladesh)

humidity ranged between 70-80%. The acceptable relative humidity range can be increased by adding ventilation into the mix.

Energy and carbon implications of urban warming in warm humid areas

The relationship between UHI and key urban variables such as thermal properties, urban geometries and anthropogenic heating indicates that the energy consumption required for cooling the urban effect is likely to increase with urban growth especially during summertime and in larger urban areas in warm climates (see, Zhang et al., 2009). The need for spatial cooling energy remains suppressed in the warm humid region largely due to high energy prices and limited economic growth, coupled with relatively low urban share of the population at present. With increasing urbanisation and affluence, a warming trend (global and local) will see a massive increase in the use of air conditioning. Given the likely scale of the problem, there may not be any carbon-neutral solution (such as the meeting the energy demand with renewable technologies).

Design strategies to ameliorate urban warming in warm, humid cities

Urban design and planning strategies targeting the amelioration of urban warming in warm, humid cities are rare. It is even rarer to see an explicit link being made with urban warming strategies and the adaptation to global/regional warming in the region. Among cities with warm climates, Japanese cities lead the way in using UHI mitigation as an expressly global-warming adaptation approach (see for example, CASBEE – Heat Island, CASBEE-HI, JGBC, 2006).

An empirical evaluation of the effect of urban morphology on local climate in Beijing in summer (baseline daily mean = 24.9oC; daily maximum air temperature = 30.2oC) by Zhao et al., (2011) found that three planning indicators – building density as given by Floor Area Ratio, building height and green cover can explain nearly 99% of the local micro climate differences (surface temperature, peak temperature and time of day of occurrence of peak temperature). Given the similarities of the summer conditions in Beijing and central Japan cities to typical conditions in warm, humid climates, it is likely that the manipulation of the following three could lead to greater reduction in local warming in warm, humid cities: Shade, ventilation and green cover.

A. Shade

Evidence from the warm, humid tropics as well as from cities with warm, humid summer conditions indicate that shade (either caused by buildings or trees) to be the single most important design parameter in determining local warming/ cooling as the radiative flux from direct sunlight has a strong influence on the heat balance of the body (Taylor and Guthrie, 2008). The worst street-level comfort conditions in warm, humid regions are associated with wide streets lined with low-rise buildings and no shade trees (Emmanuel and Johansson, 2006; Erell, 2008). The most comfortable conditions are associated with narrow streets and tall buildings, especially if shade trees are also present.

B. Ventilation

Ventilation has been a key strategy for thermal comfort and pollution dispersal in hot climates from ancient times. However, the low levels of wind speeds in the tropics due to the passing of the inter-tropical convergence zone twice a year makes it necessary to carefully map out the ventilation strategy at a city-wide level to induce sufficient air movement, both for pollution dispersion as well as thermal comfort. It will also enhance the cooling potential of naturally ventilated buildings (which is the commonest approach to indoor cooling in the warm, humid tropics). Hong Kong's approach to a city-wide ventilation strategy via the 'Air Ventilation Assessment' (AVA) method (Ng, 2009) best exemplifies such a planning assessment method.

Another strategy to induce street-level ventilation is to use the differences in surface temperatures of vertical surfaces of buildings in high density areas (see, Yang and Li, 2009).

C. Urban greenery

The importance of urban greenery to human comfort at street level is long recognised. However efforts to use greenery to ameliorate urban warming need to be cognizant of the scale of the effect due to different kinds of greenery, limitations of its use and the unintended consequences that might arise by their haphazard deployment.

Perhaps a meta-review conducted by Bowler et al., (2010) on the purported effect of urban greenery best sums up the findings to-date. Noting the nature of observational studies on urban green effect (small numbers of green sites), Bowler et al., (2010) concluded that 'the impact of specific greening interventions on the wider urban area, and whether the effects are due to greening alone, has yet to be demonstrated.' Further empirical research is necessary in order to efficiently guide the design and planning of urban green space, and specifically to investigate the importance of the abundance, distribution and type of greening. It is also necessary to be mindful of the interference urban greenery could cause to street-level pollution removal, especially on the leeward side of urban canyons (Gromke et al., 2008; Salim et al., 2011) as well as the enhanced water use that might be required to maintain the green cover (Gober et al., 2010).

D. Albedo

In the typically low wind speeds prevalent in tropical cities, the effect of facade materials and their colours assume greater significance. Priyadarshani et al., (2008) found that low albedo facade materials in Singapore led to a temperature increase of up to 2.5oC at the middle of a narrow canyon. Emmanuel and Fernando (2007) found that high albedo could make sunlit urban street canyons up to 1.2oC cooler in Colombo, Sri Lanka.

However, it is important to keep in mind that albedo enhancement strategies, like urban greening, are more likely to show improvements in air temperatures than thermal comfort (Emmanuel et al., 2007). From an urban design point of view, mitigation options ought to focus on thermal comfort enhancement (including the MRT) rather than merely attempting to control air temperatures (Emmanuel and Fernando, 2007).

A more promising approach to cool the many dark surfaces in cities that cannot be effectively shaded is the use of the so-called cool materials (either low albedo or phase change materials – PCMs). Synnefa et al., (2011) showed that PCMs can effectively reduce surface temperatures of dark asphalt surfaces in cities (typically these are 'hard-to-treat'). The added advantage of PCMs is that they are available in many colours, thus eliminating the need for white surfaces (with their attendant maintenance problems in humid environments). These strategies could not only reduce building energy consumption but could also lead to citywide lowering of ambient air temperatures, slowing ozone formation and increasing human comfort.

Design implications

A recent simulation exercise using the SHIM Model and ENV-met simulations (Emmanuel et al., 2011) of the likely urban warming effects of the planned urban growth trajectories in the warm, humid city of Colombo, Sri Lanka indicates that there are significant differences in the likely warming rates between different urban growth trajectories. A moderate increase in built cover appears to lead to the least amount of warming. At the neighbourhood scale streets oriented to the prevailing wind directions with staggered building arrangements together with street trees appear to offer the best mitigatory possibility to deal with urban warming in warm humid cities. A combined approach of all of the above could in theory, eliminate the warming effect due to the heat island phenomenon.

Urbanisation has consequences not only on local warming but also on regional and perhaps global warming. The rapid development of tropical megacities poses a special problem in terms of managing such local warming from reaching the regional/global scale. However they also present an opportunity in that the increasing urban growth and associated infrastructure development could be used as a first line of defence against the vagaries of climate change. Such action remains within the urban planning and design domain and the phenomenon of UHI provides both a focal point as well as a political/policy opportunity to cities to contribute to the issue of adaptation to climate change. As Oke (1997) pointed out the scale of climate modifications that have occurred in urban areas is of similar rate and magnitude to the climate change expected over this century due to increasing greenhouse gases. Given our results (of likely cooling from a judicious use of shading, ventilation and urban greenery), it is possible to learn planning lessons that could potentially eliminate the likely global warming effects expected in warm, humid cities. Furthermore, UHI mitigation provides an opportunity to 'localise' climate change action since it is technically legitimate (as we have shown above) while also being politically more accountable (see, Corburn, 2009).

Given the links between sprawling cities and urban warming (see, Stone et al., 2010), our own work in the tropics show that highly compact neighbourhoods with carefully designed densities and greenery to shade and ventilate streets may offer an important tool for adapting to the heat-related health effects associated with ongoing and future climate change.

Mills (2006) suggested that for urban climate knowledge to be better utilised in sustainable urban design (and by extension, cites adapted to climate change), the following must be met:

1. The needs of designer (e.g. existing built forms and individual building needs),
2. A range of outdoor urban spaces,
3. The links between indoor and outdoor air,
4. Outdoor levels of comfort,
5. Case-studies that link design decision to measurable impacts and,

The utilisation of urban climate knowledge for better city planning needs action from the research community, planners and decision makers and other stakeholders:

<u>From the urban climate research community:</u>

Make a stronger case linking the building 'in' to the urban 'out'
Treat outdoor comfort as a quality-of-life issue
Reflect the needs of designer (e.g. existing built forms and individual building needs)
Develop strategies for a range of outdoor urban spaces
Create database of 'case studies' that link design decision to measurable impacts (need measurement & analysis protocols)

<u>From the decision makers:</u>

Political champions for heat island mitigation in the tropics

Patience, prudence and institutional mechanisms to be ‘in it’ for the long haul

Identify early win-wins

View UHI mitigation as a global climate change adaptation mechanism

Other stakeholders:

Increased awareness of the changed climate context

Urban climate well being as a common good

Willingness-to-pay

Concerted action to help cities tackle local warming can showcase the possibilities of local action to tackle local warming. Such cities can then be used as test beds for assessing the impacts of, and adaptation strategies to, climate change on both local and global scales.

REFERENCES

Ahmed KS. 2003. Comfort in urban spaces: defining the boundaries of outdoor thermal comfort for the tropical urban environments, Ener. Build. 35, pp. 103-110Bowler et al., (2010

Christensen JH. et al. 2007. Regional climate projections, in Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by S. Solomon et al., pp. 847–940, Cambridge Univ. Press, Cambridge, U. K.

Corburn J. 2009. Cities, climate change and urban heat island mitigation: localising global environmental science. Urban Studies, 46, pp. 413–427

Emmanuel R. 2005. An Urban Approach to Climate Sneistive Design: Strategies for the Tropics. London: E & FN Spon Press

Emmanuel R. Perera NGR, Maduwanthi H. 2011. Mitigating urban warming as an adaptation strategy to climate change in the warm, humid tropics. Build. Env. (in review)

Emmanuel R, Fernando HJS. 2007. Urban heat islands in humid and arid climates: role of urban form and thermal properties in Colombo, Sri Lanka and Phoenix, USA. Clim Res. 34, pp. 241–251

Emmanuel R, Johansson EJ, Rosenlund H. 2007. Urban shading – a design option for the tropics? A study in Colombo, Sri Lanka. Int. J. Climatol. 27, pp. 1995–2004

Emmanuel R, Johansson EJ. 2006. Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka. Clim. Res. 30, pp. 189–200

Erell E. 2008. The application of urban climate research in the design of cities. Advances in Building Energy Research, 2, pp. 95-121

Gober P, Brazel A, Quay R, Myint S, Grossman-Clarke S, Miller A, Rossi S. 2010. Using watered landscapes to manipulate urban heat island effects: how much water will it take to cool Phoenix? J. Am. Plan. Assoc. 76, pp. 109–121Grimmond et al., 2010

Grimmond CSB, Roth M, Oke TR, Au YC, Best M, Betts R, Carmichael G, Cleugh H, Dabberdt W, Emmanuel R, Freitas E, Fortuniak K, Hanna S, Klein P, Kalkstein LS, Liu CH, Nickson A, Pearlmutter D, Sailor D, Voogt J. 2010. Climate and more sustainable cities: climate information for improved planning and management of cities (Producers/Capabilities Perspective). Procedia Environmental Sciences, 1, 247–274

Grimmond S. 2007. Urbanization and global environmental change: local effects of urban warming. Geographical Journal, 173, pp. 83-88

Gromke C, Buccolieri R, Di Sabatino S, Ruck B. 2008. Dispersion study in a street canyon with tree planting by means of wind tunnel and numerical investigations – evaluation of CFD data with experimental data. Atmos. Env. 42, pp. 8640–8650

Japan Green Build Council (JaGBC) and Japan Sustainable Building Consortium (JSBC).2006. CASBEE for heat island (CASBEE-HI). Japan: JaGBC and JSBC (Availablefrom: http://www.ibec.or.jp/CASBEE/index.htm, accessed 12 May 2011)/; 2006.

Jauregui E. 1993. Bibliography of Urban Climate in Tropical/ Subtropical Areas, 1981–1991, WCASP-25, WMO/TD-No. 552. World Meteorological Organisation: Geneva; 87

Jauregui E. 1996. Bibliography of Urban Climatology for the Period 1992–1995 Including a Special Section on Urban Climate in Tropical/ Subtropical Areas, WCASP-36, WMO/TD-No. 759. World Meteorological Organisation: Geneva

Mills G. 2006. Progress towards sustainable settlements: a role for urban climatology. Theoretical and Applied Climatology, 84, pp. 69–76

Ng E. 2009. Policies and technical guidelines for urban planning of high-density cities – air ventilation assessment (AVA) of Hong Kong. Build. Environ. 44, pp. 1478–1488

Nieuwolt S. 1966. The urban microclimate of Singapore. J. Trop. Geog. 22, pp. 30-37

Oke TR. 1997. Urban climates and global change. In, Perry A and Thompson R (eds). Applied Climatology: Principles and Practices, pp. 273–287. London: Routledge

Priyadarsini R, Wong NH, Cheong KWD. 2008. Microclimatic modelling of the urban thermal environment of Singapore to mitigate urban heat island. Solar Energy. 82, pp. 727–745

Roth M. 2007. Review of urban climate research in (sub)tropical regions, Int. J. Climatol. 27, pp. 1859–1873

Salim SM, Cheah SC, Chan A. 2011. Numerical simulation of dispersion in urban street canyons with avenue-like tree plantings: Comparison between RANS and LES. Build. Env. 46, pp. 1735–1 746

Stone B, Hess JJ, Frumkin H. 2010. Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? Env. Health Pers. 118, pp. 1425 – 1428

Svirejeva-Hopkins A, Schellnhuber HJ, Pomaz VL. 2004. Urbanised territories as a specific component of the global carbon cycle. Ecological Modelling, 173, pp. 295–312

Synnefa A, Karlessi T, Gaitani N, Santamouris M, Assimakopoulos DN, Papakatsikas C. Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate. Build. Env. 46, pp. 38–44

Taylor B, Guthrie P. 2008. The first line of defence: Passive design at an urban scale. Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, UK, 27-29 July 2008. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk (accessed 15 Feb 2010)

United Nations, Department of Economic and Social Affairs, Population Division (2010). World Urbanization Prospects: The 2009 Revision. CD-ROM Edition – Data in digital form (POP/ DB/WUP/ Rev.2009)

Yang L, Li Y. 2009. City ventilation of Hong Kong at no-wind conditions. Atmos. Env. 43, pp. 3111–3121

Zhang P, Imhoff ML, Wolfe RE, Bounoua L. 2009. Characterizing urban heat island effect at global settlements using MODIS and nightlight products. Paper presented at the American Geophysical Union, Fall Meeting 2009, abstract #U33B-0054 (can be accessed at: http://adsabs.harvard.edu/abs/2009AGUFM.U33B0054Z, last accessed 11 April 2011)

Zhao C, Fu G, Liu X, Fu F. 2011. Urban planning indicators, morphology and climate indicators: A case study for a north-south transect of Beijing, China. Build. Env. 46, pp. 1174–1183